IR refocusing: collector mirror design

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The Netherlands

FOM DIFFER/Rijnhuizen

Multilayer R & D program

EUV & Beyond lithography

XFEL applications

Figure 1.
The front entrance of FOM-Rijnhuizen.

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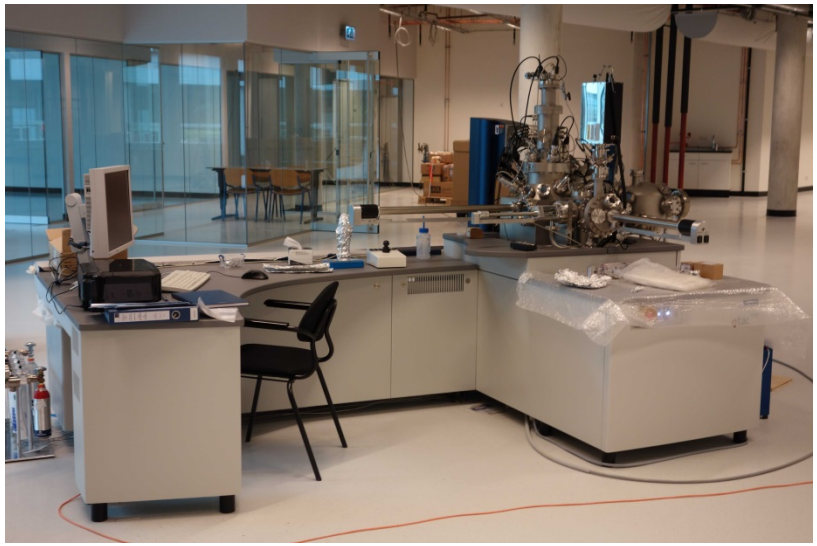
University of Twente / MESA+



XUV OPTICS

Focus Group in Twente

Multilayer R & D program
University of Twente
MESA+ Institute for Nanotechnology

SolMateS

provincie Overijssel

DEMCON

PANalytical

norma

XUV

STW

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LPNO Laser Physics and Nonlinear Optics

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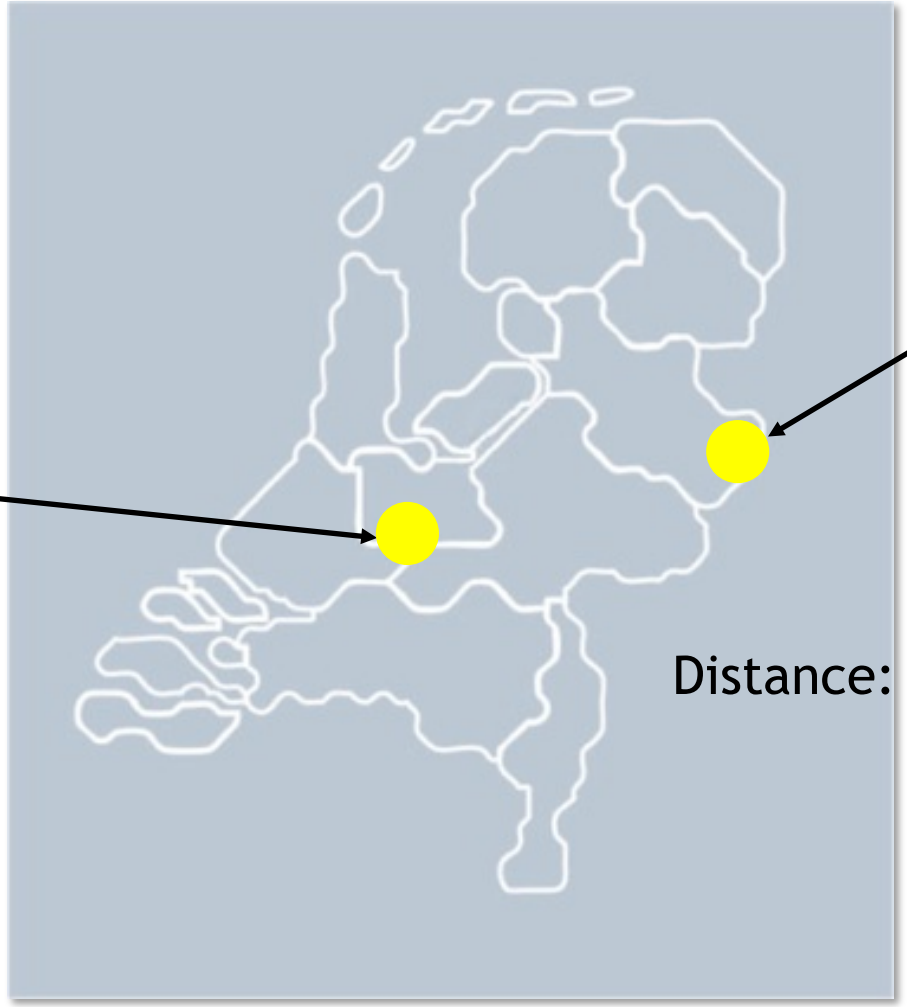
Location in the Netherlands



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Distance: 145 km or 90 miles

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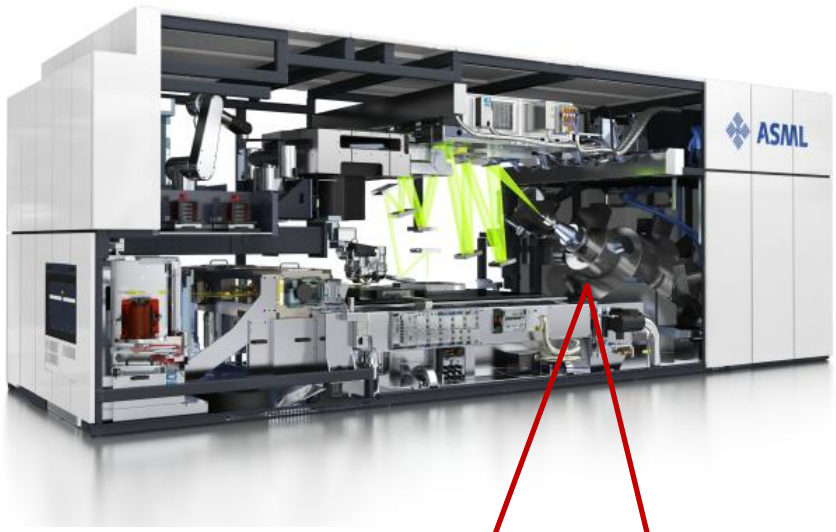
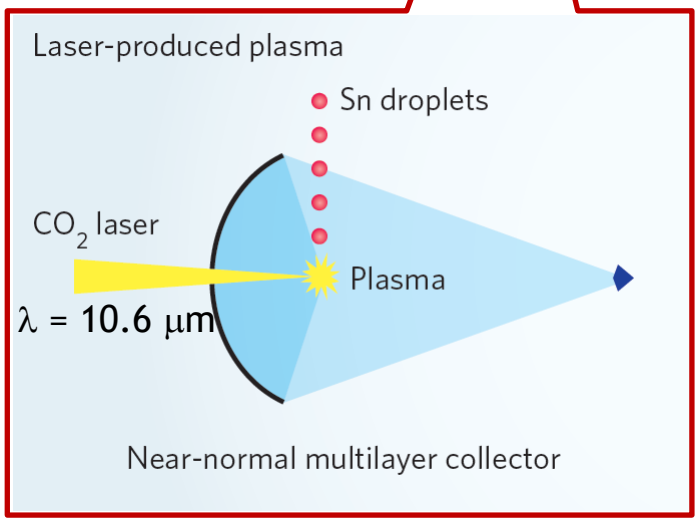
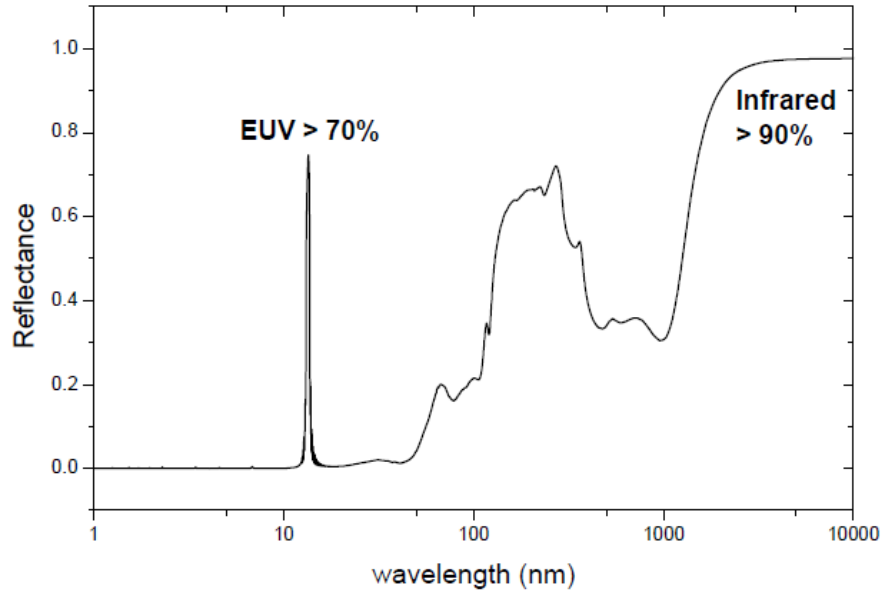
Laser-produced plasma 13.5 nm EUV source





Mo/Si reflectance



Mo/Si optics: High reflectance for 10.6 μm laser radiation

Reflected CO_2 laser radiation propagates along with EUV light:

→ Heat loads on projection optics

→ Heat loads on wafer stage

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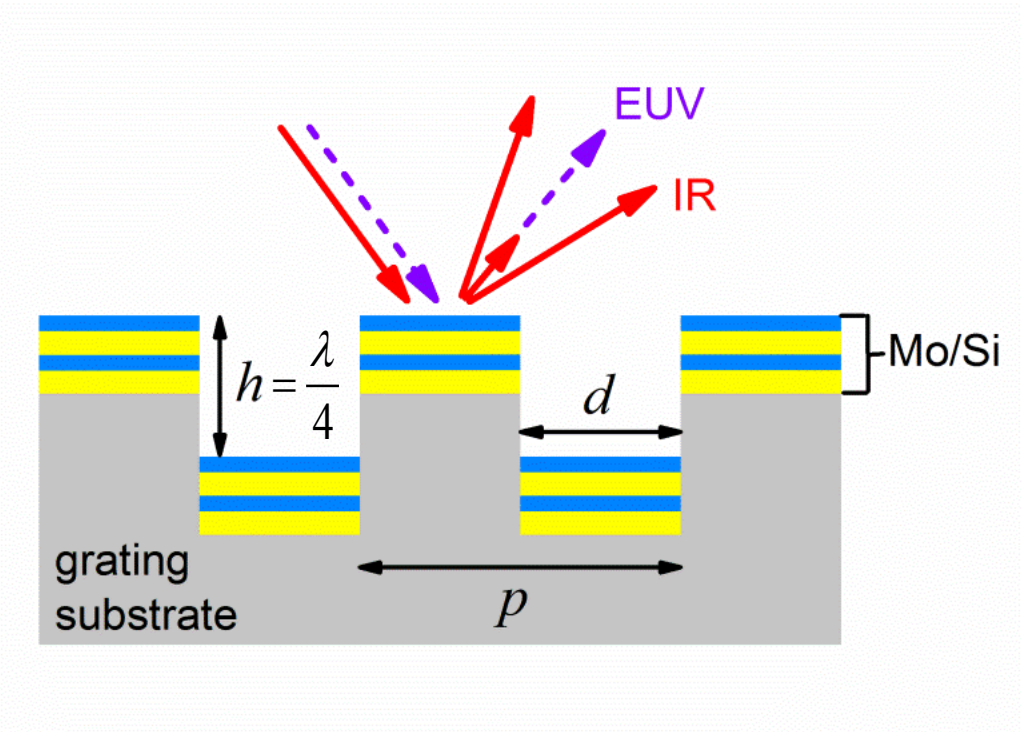
Proven concept: Grating-based IR suppression



Destructive interference for the specular direction

zero order IR reflectance: $R^{(0)} = 0$

Reflected IR radiation is distributed between off-specular diffraction orders

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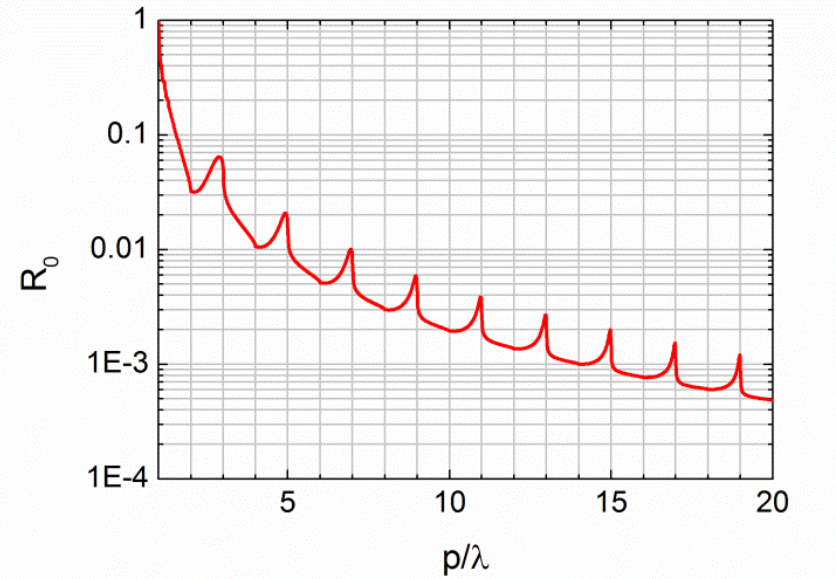
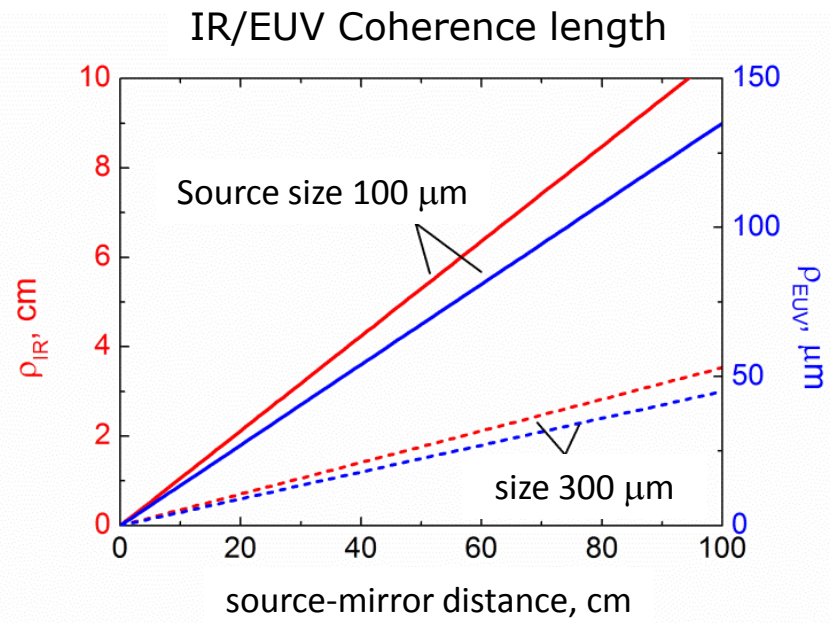
Choice of geometrical parameters

- h = λ/4 (10.6/4 μm) – out-of-phase
- duty cycle (d/p) = 0.5
- period (p) = ???





Grating period ~ 100 μm

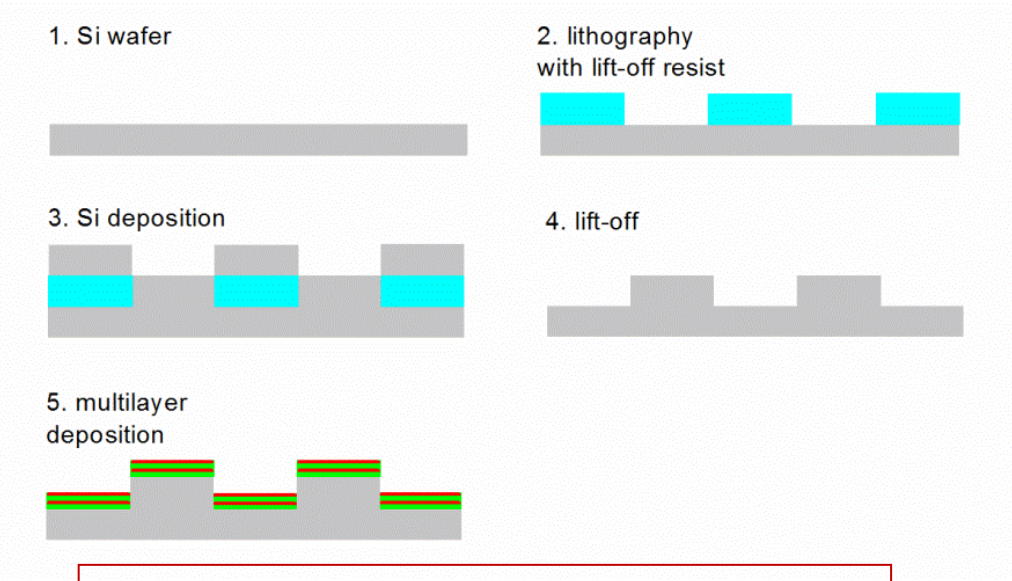
IR suppression > 100x (calculated for perfect infinite grating)

IR coherence length 1-10 cm >> period -> IR diffracted

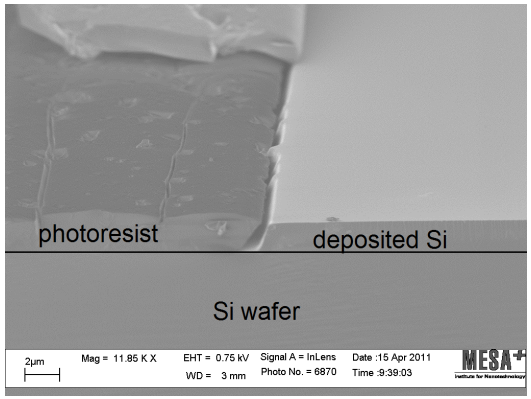
EUV coherence length 10-100 μm ≤ period -> EUV non-diffracted

Fabrication of test structures

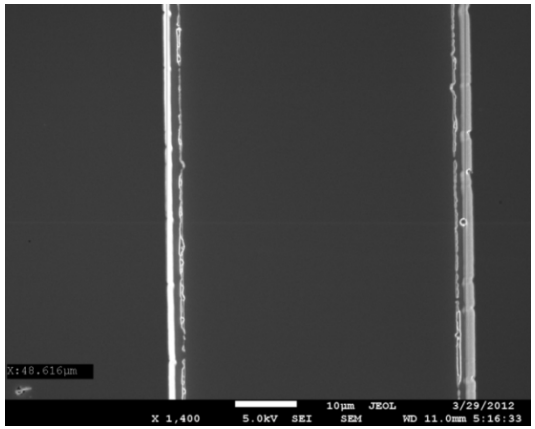
Fabrication steps



SEM: fabrication step #3



SEM: fabrication step #5



Test structures:

p = 100 μm

→ Diffraction angle at 10.6 μm $\theta \approx 6°$

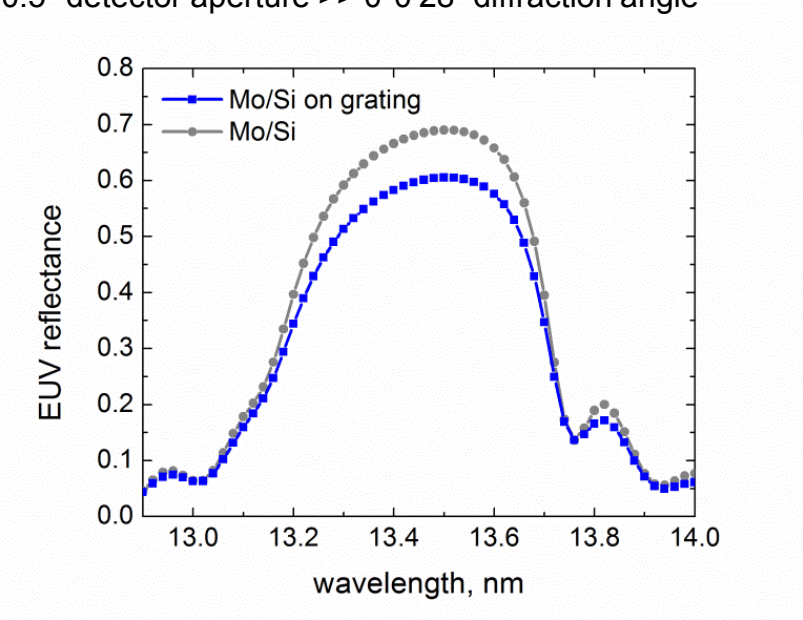
h = 2.35 μm ± 0.05 μm (AFM measured)

→ Reflectance minimum at $\lambda \approx 9.4$ μm

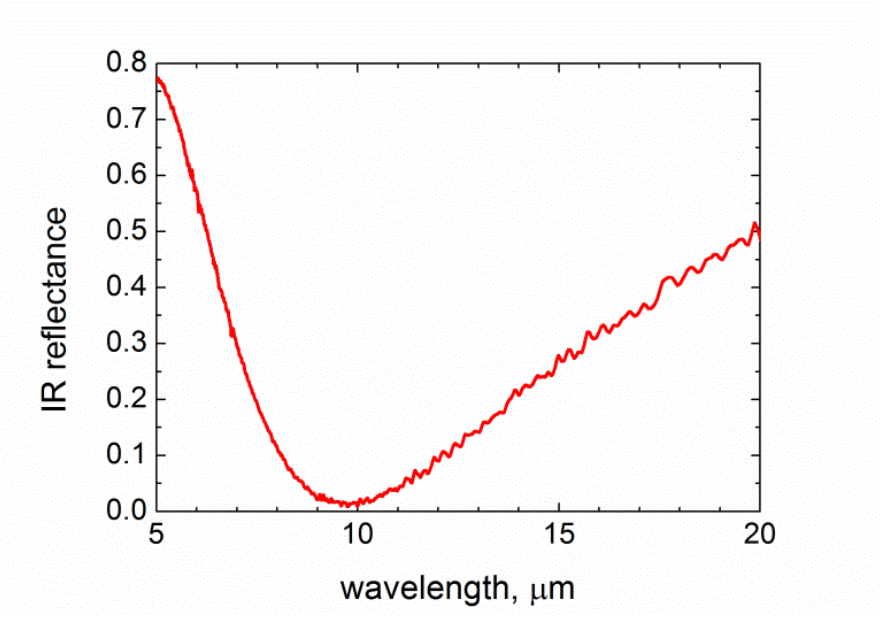
V.V. Medvedev et al., *Opt. Express* **21** 16964 (2013)

Measured spectral characteristics

Measured at PTB
1.5º from normal
0.5º detector aperture >> 0º0'28" diffraction angle



Measured with FTIR spectrometer
Off-specular reflectance filtered with diaphragm



61% EUV peak reflectance

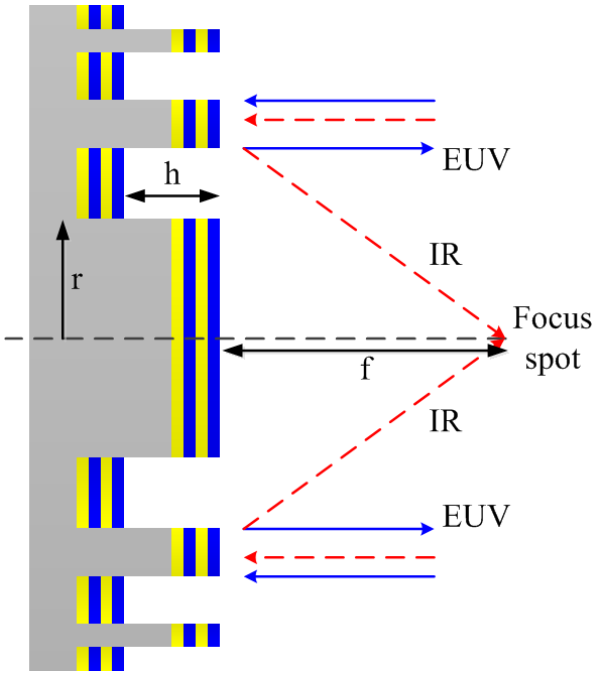
8% losses due to structure/multilayer imperfections

70x IR suppression at 9.7 μm

V.V. Medvedev et al., *Opt. Express* **21** 16964 (2013)

Focusing gratings: Fresnel Zone Plates

Cross-section

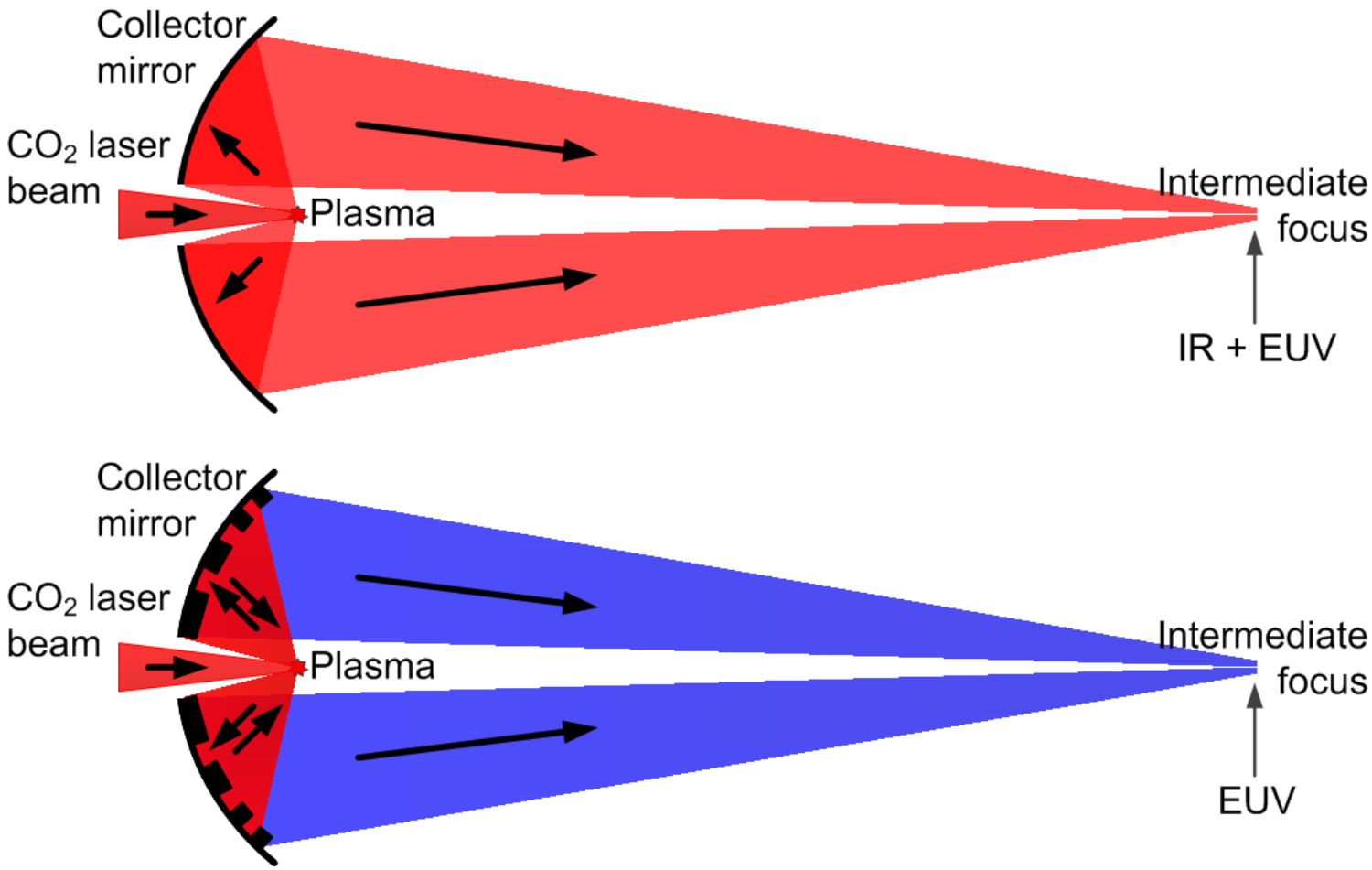


Front view

Two dimensional grating effect
Non-periodic, radius is larger at the center
Theoretical zero-order reflectance = 0

IR light from the collector is focused to plasma
Minimal effect on the EUV light

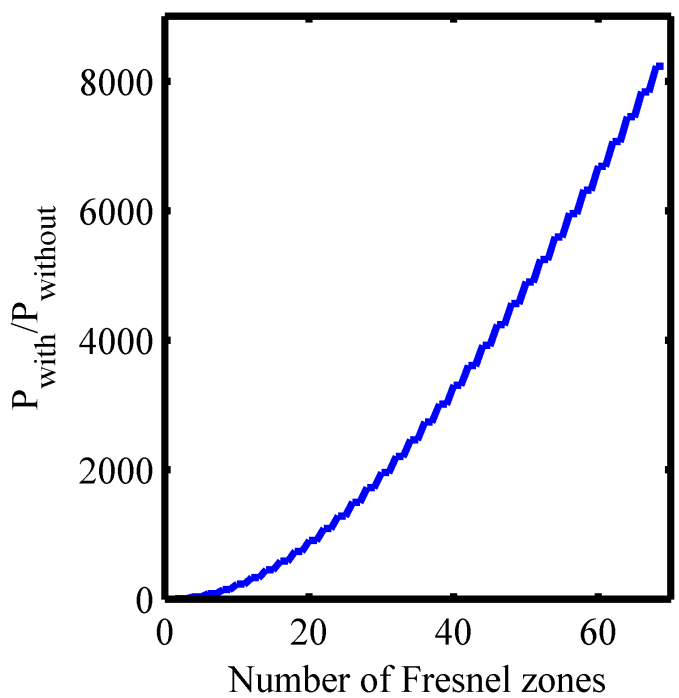
Fresnel zone plate on collector



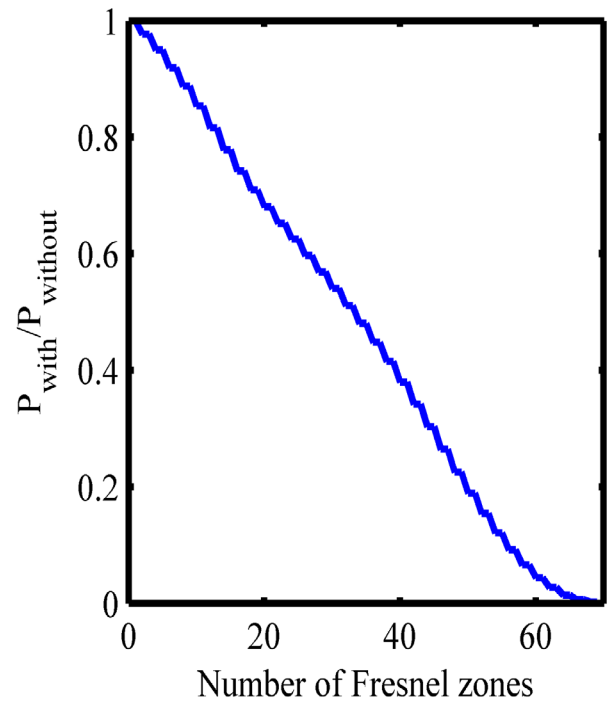
re-usage of wasted IR + removal of IR from IF position

Efficiency of IR re-usage

IR power refocused in plasma position

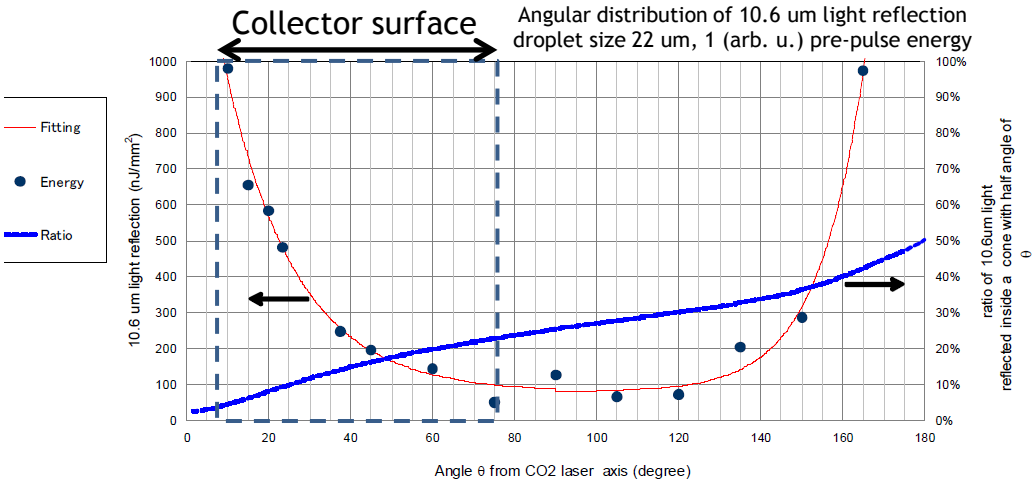


IR power at intermediate focus



- *More than 8000 times increase of IR power redirected to plasma*
- *IR power in intermediate focus practically zero*

Focusing effect



(Fujimoto et al, Gigaphoton, Proc. SPIE, 2012)

- Scattering is high towards the center of the collector
- Fresnel zone plate can focus 40% of the incoming IR light to the plasma

2 steps: 40%

Focusing efficiency can be increased by multiple phase steps:

4 steps: 80%

8 steps: 95%

- ➢ *If 35-40% IR light scattering to the collector, 16% can be refocused to the plasma*
- ➢ *16% increase of IR power for free!*

Summary

- ✓ Periodic Phase Shift Grating:
  - → 70x IR suppression
  - → 61% EUV reflectance achieved, to be improved

- ✓ Possibility to refocus the IR light scattered onto the collector back to the plasma:
  - >> 2 orders suppression of the IR light at the intermediate focus
  - Up to 40% of the IR scattered light can be refocused to the plasma → free extra plasma heating

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Acknowledgement

CP3E Controlling Photon and Plasma Induced Processes at EUV optical surfaces
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